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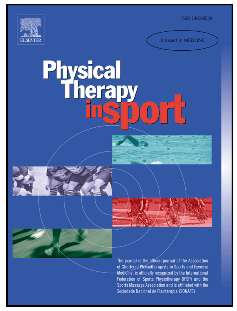

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Guillermo Mendez-Rebolledo [a, b, f, *], Valeska Gatica-Rojas [a], Eduardo Guzman-Muñoz [b], Eduardo Martinez-Valdes [c, d], Rodrigo Guzman-Venegas [e], Francisco Jose Berral de la Rosa [f]

[a] Human Motor Control Laboratory, Department of Human Movement Sciences, Faculty of Health Sciences, Interdisciplinary Excellence Research Program on Healthy Aging (PIEI-ES), Universidad de Talca, Talca, Chile.

[b] Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Chile.

[c] Centre of Precision Rehabilitation for Spinal Pain (CPR Spine), School of Sport, Exercise and Rehabilitation Sciences, College of Life and Environmental Sciences, University of Birmingham, Birmingham, UK.

[d] Centro de Investigacion en Fisiologia del Ejercicio (CIFE), Universidad Mayor, Santiago, Chile.

[e] Laboratorio Integrativo de Biomecánica y Fisiología del Esfuerzo (LIBFE), Universidad de Los Andes, Santiago, Chile.

[f] Universidad Pablo de Olavide, Seville, Spain.

*** Corresponding author.** Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Chile. E-mail address: guillermomendezre@santotomas.cl (G. Méndez-Rebolledo).

E-mail addresses: guillermomendezre@santotomas.cl (G. Mendez-Rebolledo); vgatica@utalca.cl (V. Gatica-Rojas); eguzmanm@santotomas.cl (E. Guzman-Muñoz); e.a.martinezvaldes@bham.ac.uk (E. Martinez-Valdes); rguzman@uandes.cl (R. Guzman-Venegas); fjberde@upo.es (FJ Berral de la Rosa).

Influence of Fatigue and Velocity on the Latency and Recruitment Order of Scapular Muscles

Abstract

Objectives: To determine the influence of velocity and fatigue on scapular muscle activation latency and recruitment order during a voluntary arm raise task, in healthy individuals.

Design: Cross-sectional study.

Setting: University laboratory.

Participants: Twenty three male adults per group (high-velocity and low-velocity).

Main outcome measures: Onset latency of scapular muscles [Anterior deltoid (AD), lower trapezius (LT), middle trapezius (MT), upper trapezius (UT), and serratus anterior(SA)] was assessed by surface electromyography. The participants were assigned to one of two groups: low-velocity or high-velocity. Both groups performed a voluntary arm raise task in the scapular plane under two conditions: no-fatigue and fatigue.

Results: The UT showed early activation ($p < 0.01$) in the fatigue condition when performing the arm raise task at a high velocity. At a low velocity and with no muscular fatigue, the recruitment order was MT, LT, SA, AD, and UT. However, the recruitment order changed in the high-velocity with muscular fatigue condition, since the recruitment order was UT, AD, SA, LT, and MT.

Conclusions: The simultaneous presence of fatigue and high-velocity in an arm raise task is associated with a decrease in the UT activation latency and a modification of the recruitment order of scapular muscles.

Keywords: Timing; Neuromuscular control; Speed; Recruitment pattern.

Highlights:

- Upper trapezius shows an early activation latency with the simultaneus presence of fatigue and high velocity
- Muscle recruitment order is modified during an arm raise task at different velocities.
- Muscle fatigue or an increase in velocity alone do not subtantially modify activation latency

1. Introduction

The balance between the trapezius and serratus anterior (SA) muscles maintains the dynamic stability of the scapula during arm movement (Ludewig et al., 2004; Kibler et al., 2007; Larsen et al., 2013; Hwang et al., 2017; Kara et al 2017). These functions depend on muscle strength and appropriate motor control, i.e., appropriate onset latency (timing) and muscle recruitment order (Cools et al., 2003; Phadke & Ludewig, 2013; Struyf et al., 2014). In the scapular muscles, the onset latency has been typically quantified as the time between the electromyographic (EMG) activation of a specific muscle and the activation of the anterior deltoid which is the primary motor muscle (Phadke & Ludewig, 2013). Thus, the latency of the muscles surrounding the scapula, and their recruitment order during the execution of a motor task, can be calculated.

To our knowledge, there are few reports on the influence of velocity of movement on scapular muscle activation latency and recruitment order. It has been observed that the scapulohumeral rhythm has a ratio of 2:1 during movements at low-velocity (Sugamoto et al., 2002; Prinold et al., 2013), while during movements at high-velocity, the scapular contribution is higher (Sugamoto et al., 2002). On the other hand, Roy et al. (2008) showed that the activation latency of the scapular muscles, under a condition of no-fatigue, is modified at different arm raise velocities (Roy et al., 2008). Thus, there is inconsistency in the reported influence of velocity on scapular muscle motor control strategies.

Instability (Myers et al., 2004), the “subacromial impingement” syndrome (Cools et al., 2003; Phadke & Ludewig, 2013), the level of contraction (Myers et al., 2003), and pain (Santos et al., 2010) are all factors that affect the activation latency of the glenohumeral and scapular muscles. It is possible that scapular motor control is most demanding with high-velocity movements (Sugamoto et al., 2002; Thomas et al., 2003) and with the simultaneous presence of other physiological factors, e.g., fatigue and pain (Santos et al., 2010). In this context, a late scapular muscle response (i.e., latency increase) has been observed after a sudden arm fall (unpredictable) from a 90° abduction in fatigued scapular muscles (Cools et al., 2002). In a recent study, we investigated the effect of predictable and unpredictable motor tasks on scapular muscle activation latency (Mendez-Rebolledo et al., 2016). Our results indicated that scapular muscles presented a specific recruitment order during a predictable task: SA was activated prior to the anterior deltoid (AD), and the upper trapezius (UT) was activated after the AD. While in an unpredictable motor task, all muscles were activated after the destabilization, without a specific recruitment order; instead, there was simultaneous activation. These results contribute to the understanding of motor control strategies in predictable tasks; however, the mechanisms involved have not yet been reported in detail. In line with this, it is necessary to increase knowledge about the simultaneous effects of muscular fatigue and velocity increases during the arm raise task, in terms of scapular muscle activation latency and recruitment order.

These two factors (velocity and fatigue) are frequent physiological conditions that occur during daily activities, work, and sporting tasks (Thomas et al., 2003; Santos et al., 2010; Joshi et al., 2011). A better understanding of how motor control is required during predictable movements at high-velocity, and during conditions of fatigue, would allow for better planning and selection of the most appropriate outcomes and the most suitable exercises for rehabilitation plans (Santos et al., 2010; Joshi et al., 2011). Thus, the objective of the current study was to determine the influence of velocity and fatigue on scapular muscle activation latency and recruitment order during a voluntary (predictable) arm raise task, in healthy individuals. We hypothesized that the presence of fatigue in the scapular muscles, during an arm raise task at high-velocity, would modify scapular muscle activation latency and recruitment order.

2. Methods

2.1. Study design

This cross-sectional study was conducted in the XXX. The results reported here correspond to the second stage of a larger investigation. The first stage was recently published (Mendez-Rebolledo et al., 2016). The dependent variable in the current study was onset latency of the scapular muscles: lower trapezius (LT), middle trapezius (MT), UT, and SA. Independent variables included velocity (low and high) and the absence or presence of fatigue. The method was designed considering the Helsinki Consensus (1975) on biomedical research in humans. The Bioethics Committee of the XXX approved all procedures (Folio 2015106GM) and an informed consent form was read and signed by each participant before participating in the study.

2.2. Participants

The participants presented the following baseline characteristics: age, 21.4 ± 1.6 years; height, 1.72 ± 0.05 m; weight, 72.4 ± 6.4 kg; body mass index (BMI), 24.4 ± 2.9 kg/m^2; and physical/sporting activity, 3 ± 1.2 times per week. The study involved a non-probability sample of students from the Facultad de Ciencias de la Salud de la Universidad de Talca recruited via advertising. A sample of 23 voluntary participants per group (high and low velocity) was calculated based on a 95% confidence interval, a power of 0.8, and an expected 15% loss. A mean of 159.6 ms and a standard deviation of 56.4 ms for UT onset latency was obtained in a previous study (Cools et al., 2002), and was considered for the sample size calculation. Exclusion criteria were: (1) BMI greater than 29.9 kg/m^2, as the extra subcutaneous tissue can compromise the quality of the EMG signal (Phadke & Ludewig, 2013); (2) incomplete range of motion of the shoulder; (3) a current or past history of shoulder pain; (4) participation in overhead sports; and (5) history of trauma, dislocation, rotator cuff tear, spinal deformities, radicular symptoms, and/or neurological diseases.

2.3. Instrumentation

An accelerometer (Delsys Inc., Boston, MA, USA) was used on the anterior deltoid's surface of each volunteer to determine the beginning and end of the elevation movement. This procedure was modified from previous reports where different movement tasks were measured (Körver et al., 2014). The surface EMG (sEMG) signal was acquired with a Delsys Trigno™ Wirless EMG System (Delsys Inc., Boston, MA, USA) and recorded with the EMGworks Acquisition 4.2.0 (Delsys Inc., Boston. MA, USA) software. The sEMG was sampled at 2000 Hz and stored on a computer using a 16-bit analog-digital converter. The electrodes were made of silver (99.9%) and had an inter-electrode distance of 10 mm. A bandpass filter was used (fourth-order, zero-delay butterworth filter with frequencies between 20-450 Hz) and the signal was digitally amplified with a gain of 300, common mode rejection ratio > 80 dB, signal-to-noise ratio < 0.75 mV RMS.

2.4. Procedures and data collection

Anthropometric assessments of the participants (weight and height), and warm-up exercises of the scapular and rotator cuff muscles, were performed at the beginning of each session (day 1 and 2). Prior to electrode placement, the hair was shaved and the skin was cleaned with dermoabrasive paper and 70% isopropyl alcohol solution, to reduce the impedance (typically $\leq$ 10 kΩ). The EMG signals were recorded from the dominant arm; the electrodes were located on the UT, MT, LT, SA, and AD muscles. The electrodes were placed parallel to the presumed direction of the muscle fibers, according to SENIAM recommendations (Hermens et al., 2000). For the SA, electrodes were placed according to a previous study (Lehman et al., 2008). The position of each electrode on the skin was marked with a hypoallergenic pencil to ensure the location of the electrodes. Finally, an accelerometer was placed in the lateral region of the arm. Proper electrode placement was further verified by observing the EMG signal on a computer monitor during maximal voluntary isometric contraction of the arm, according to the SENIAM recommendations.

The participants were assigned through simple random sampling (random number generator) to one of two groups: low-velocity or high-velocity. Both groups performed a voluntary arm raise task in the scapular plane under two conditions: no-fatigue and fatigue (Fig. 1). A custom-made device based on previous studies (Ludewig & Cook, 2000; Moraes et al., 2008) was used to standardize the upper limb position to ensure that the movement was made in the scapular plane. This device consisted in a rectangular glass positioned in front of the arm, 30° anterior to the frontal plane (scapular plane). The low-velocity group executed the task with a velocity of four seconds per cycle of arm elevation, in a range of motion of 180°, and the high-velocity group executed the task with a velocity of two seconds per cycle (Sugamoto et al., 2002). In the no-fatigue condition, the participants were instructed to reproduce the movement velocity following the established rhythm of a metronome; they practiced the movement at least two times prior to the measurements. This task was executed voluntarily, without interruptions, and in the presence of visual (opened eyes), somatosensory (gravity effect on the upper limb) and auditory information (metronome), in order to ensure the task was "predictable" (Kanekar & Aruin, 2015). Participants rested for 5 min before completing the fatigue condition.

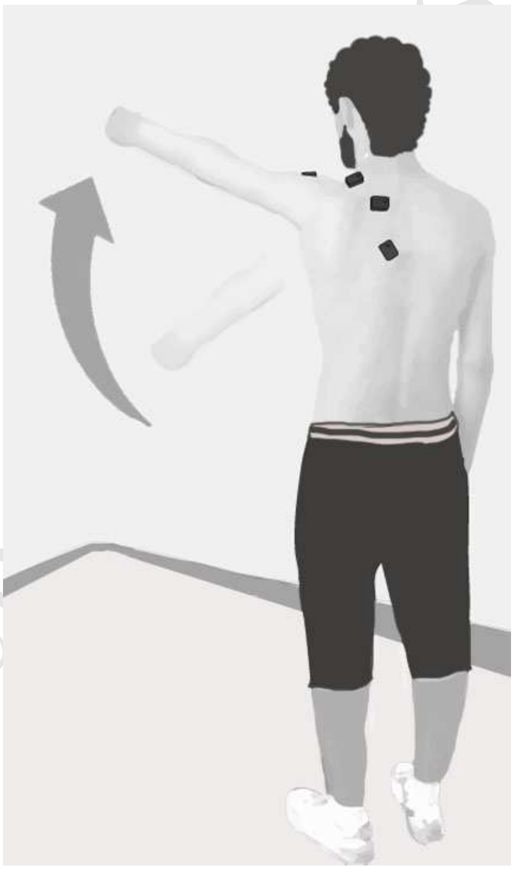


Fig. 1. Voluntary arm raise task: voluntary arm elevation of 180° with the glenohumeral joint at 30° of horizontal adduction.

Each participant was given instructions about the fatigue protocol for shoulder muscles. This protocol consisted of execution of a cycle of bilateral arm elevation (180°) in the scapular plane (describe above) at a rate of 1 cycle per second, as many times as possible. The movement was performed with a dumbbell according to body weight; 1.4 kg for those participants weighing less than 68.1 kg, and 2.3 kg for those participants weighing greater than 68.1 kg. The use of this criterion allowed us to observe alterations in scapular movement in participants performing an arm raise task against a resistance based on their body weight (McClure et al., 2009). Enoka (2012) indicated that the fatigue experienced by an individual depends on both perceptions of fatigue and the level of fatigability. For these reasons, each participant was provided with instructions regarding the modified Borg's Rate of Perceived Exertion Scale (Zanca et al., 2016), and time of task failure, during the fatigue protocol (bilateral arm elevation) described previously. Every 20 cycles of arm elevation, participants were asked about their level of shoulder fatigue on a scale from 0 to 10. The fatigue protocol was discontinued when the participant reached a score equal to or greater than 8, and were not able to maintain the bilateral arm elevation. Once fatigued, participants again performed the voluntary arm raise task. Finally, the EMG signals of the scapular muscles (UT, MT, LT, and SA) and the AD were recorded, and the average of three trials performed by each group, and under condition (no-fatigue or fatigue), was calculated. A signal-to-noise ratio of less than 20% was confirmed in all the signals. Additionally, the arm elevation and fall times were calculated through accelerometry. No significant differences between elevation and fall times were observed in each group (fatigue; no-fatigue) and condition (low-velocity; high-velocity).

2.5. Data processing

All raw EMGs signals were analyzed with EMGworks Analysis 4.2.0 (Delsys Inc., Boston, MA, USA). The signals were full-wave rectified and filtered with a low-pass filter (fourth-order, zero delay, butterworth filter) with a cutoff frequency of 50 Hz (Phadke & Ludewig, 2013). The onset latency variable for each scapular muscle was calculated as the difference in latency relative to that of AD activation (Phadke & Ludewig, 2013; Mendez-Rebolledo et al., 2016). Onset was defined as the point where the EMG activity passed the threshold of at least three standard deviations above the average of the signal at rest, and maintained this level of activation for at least 25 ms (Myers et al., 2003; Phadke & Ludewig, 2013). The standard deviation was calculated in relation to a period of 200 ms of rest signal. One researcher visually confirmed all muscle onset latencies.

2.6. Statistical analysis

The mean of the three trials for each group and condition (no-fatigue or fatigue) was used for the statistical analysis. To determine differences in the BMI between low-velocity and high-velocity groups, a *t*-test for independent groups was used. An alpha level <0.05 was considered in all the statistical tests. SPSS statistical software (SPSS 20.0, SPSS Inc., IL, USA) was used.

The Shapiro-Wilk test, Levene's test, and Mauchly's test of sphericity were applied to calculate the distribution, homogeneity of variance, and sphericity, respectively. To determine the interaction between velocity and fatigue, a two-way repeated measure analysis of variance (ANOVA) with within and between factors: velocity (two levels) and fatigue (two levels) was performed. When the repeated measure ANOVA showed interaction between factors, Bonferroni corrected *t*- tests were used to compare the onset latencies between factors. To determine differences between scapular muscles onset latencies in each condition, i.e. differences in the recruitment order, a one-way repeated measures ANOVA with factor muscle (four levels) was performed. Bonferroni corrected *t*-tests were used to compare the scapular muscles response.

Partial eta-squared (η_p^2) for ANOVA was used to examine the effect size. A η_p^2 less than 0.06 was classified as "small", 0.07-0.14 as "moderate", and greater than 0.14 as "large". In addition, Cohen *d* for paired samples was used as an indicator of the effect size. A Cohen *d* less than 0.2 was classified as "trivial", 0.2-0.5 as "small", 0.5-0.8 as "moderate", and greater than 0.8 as "large".

3. Results

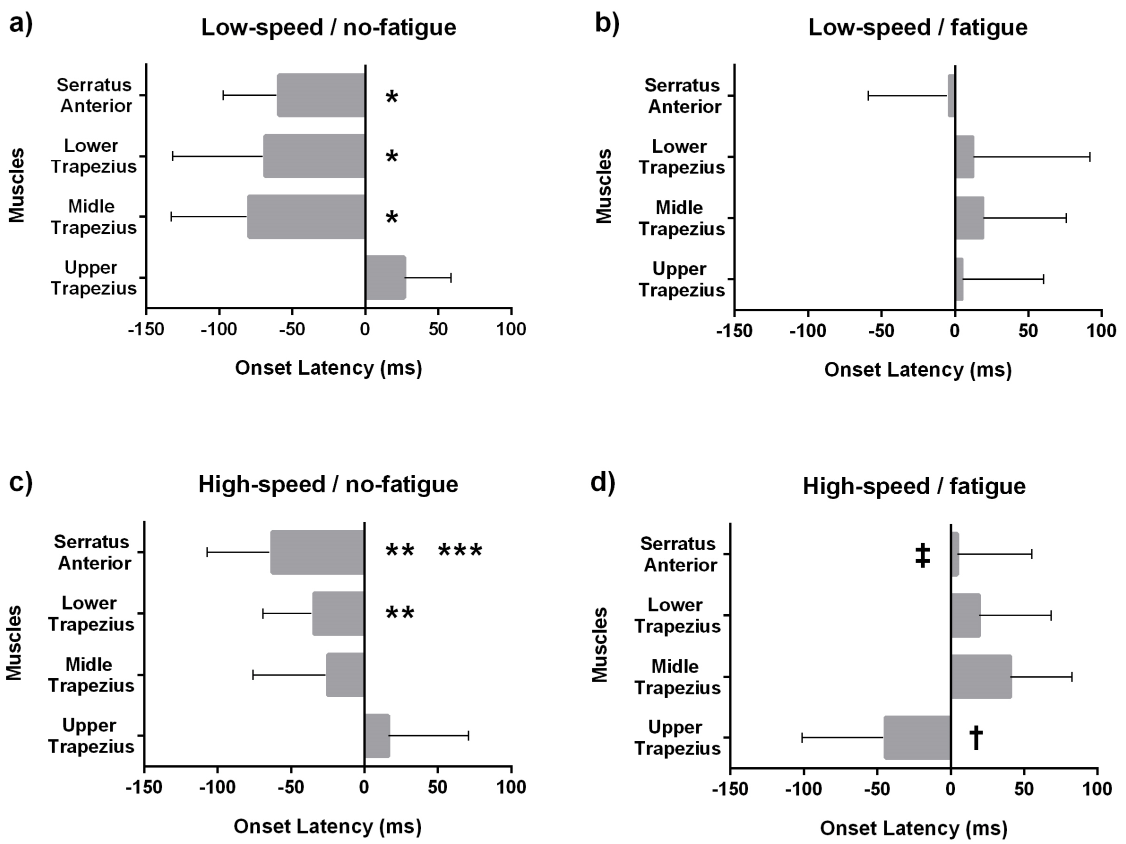
Two participants (one from each group) were not included in the analysis because these presented EMG signals with excessive noise and artifacts. Therefore, the following results consider 22 participants for each group (low-velocity and high-velocity). There were not significant differences in BMI between groups ($p > 0.05$). The time of task failure was 192 ± 79 sec for the low-velocity group and 158 ± 86 sec for the high-velocity group. All data presented a normal distribution, sphericity, and homogeneity of variance.

3.1. Influence of velocity and fatigue in scapular muscles onset latencies.

The repeated measures ANOVA revealed a significant velocity x fatigue interaction with a moderate effect size ($F_1 = 4.25$; $P = 0.045$; $\eta p^2 = 0.09$) only for UT onset latency. The post-hoc analysis showed that the UT exhibited a significantly earlier onset latency in the fatigue condition to high-velocity than in all other conditions (Table 1). The above significant differences presented a large effect size. The other scapular muscles onset latencies did not show a significant velocity x fatigue interaction: MT ($F_3 = 2.18$; $P = 0.147$; $\eta p^2 = 0.05$), LT ($F_3 = 0.45$; $P = 0.503$; $\eta p^2 = 0.01$), and SA ($F_3 = 0.49$; $P = 0.486$; $\eta p^2 = 0.01$).

3.2. Influence of velocity and fatigue in scapular muscle recruitment order.

In the no-fatigue condition of slow-velocity group, the first muscle activated was



MT, followed by the LT, SA, AD and UT (Fig. 2a). The repeated measures ANOVA showed a main effect for muscle with a large effect size (F_4 = 19.15; P<0.0001; ηp^2 = 0.81). The post-hoc analysis showed that the MT, LT and SA were activated significantly earlier than the AD and UT (Table 2). In addittion, the AD was activated significantly earlier than UT. The above significant differences presented a large effect size. In the fatigue condition of this same group, the first muscle activated was the SA, followed by the AD, UT, LT and MT (Fig. 2b). However, the repeated measures ANOVA did not revealed a main effect for muscle (F_4 = 0.91; P = 0.458; ηp^2 = 0.04).

Fig. 2. Scapular muscles onset latencies and recruitmet order in each velocity and condition; a) low-velocity/no-fatigue; b) low-velocity/fatigue; c) high-velocity/no-fatigue; d) high-velocity fatigue. Time zero represents the onset latency of anterior deltoid during the voluntary arm raise task and the error bars indicate standard deviation.

* MT, LT and SA were activated significantly earlier than the AD and UT. P < 0.0001

** SA and LT muscles were activated significantly earlier than the AD and UT. P < 0.01

*** SA was activated significantly earlier than the MT. P < 0.05

† UT was activated significantly earlier that the AD, SA, LT and MT. P < 0.01

‡ AD and SA were activated significantly earlier than the MT. P < 0.05

In the no-fatigue condition of high-velocity group, the first muscle activated was SA, followed by the LT, MT, AD and UT (Fig. 2c). The repeated measures ANOVA showed a main effect for muscle with a large effect size (F_4 = 14.93; P< 0.0001; ηp^2 = 0.41). Post-hoc analysis showed that the SA and LT muscles were activated significantly earlier than the AD and UT; and the SA was activated significantly earlier than the MT (Table 2). Conversely, in the fatigue condition of this same group, the first muscle activated was the UT followed by the AD, SA, LT and MT (Fig. 2d). The repeated measures ANOVA showed a main effect for muscles with a large effect size

(F_4 = 13.25; P< 0.0001; ηp^2 = 0.38). The post-hoc analysis revealed that the UT was activated significantly earlier that the AD, SA, LT and MT; and the AD and SA were activated significantly earlier than the MT (Table 2).

4. Discussion

Our results indicate that the velocity of movement and muscular fatigue modify activation latency and scapular muscle recruitment order during a voluntary arm raise task. Specifically, (1) activation latency of the UT muscle showed early activation in the condition of fatigue and high velocity movement, in comparison to the other conditions (no-fatigue and low velocity). In addition, (2) the order of recruitment was significantly different during the arm raise task at different velocities; at low velocity and with no muscle fatigue, the order of recruitment was MT, LT, SA, AD, and UT; at high velocity and with no muscle fatigue, the order of recruitment was SA, LT, MT, AD, and UT, exhibiting a pattern of recruitment similar to the initial condition; and finally, at high velocity and with muscle fatigue, the recruitment order was UT, AD, SA, LT, and MT, which is a considerable variation compared to the two previous conditions.

4.1. Onset latency of scapular muscles

This is the first report regarding the simultaneous influence of velocity and fatigue on scapular muscle latency and recruitment order during an arm raise task. The UT was the only muscle that exhibited a decrease in activation latency with the presence of fatigue and high velocity arm raise movements, modifying the latency from 26.8 to -44.4 ms. This result differs from previous reports. Roy et al. (2008) found that muscle activation latency of the shoulder complex did not vary with increased velocity in an arm raise task, among a sample of healthy participants. This motor task was performed in the presence of no muscular fatigue, and involved arm raises with 90° range of movement in the scapular plane. Only one report analyzed the influence of scapular muscle fatigue; this study found an increase in activation latency in the fatigued scapular muscles during sudden arm fall from a 90° position of abduction, under conditions of visual, auditory, and somatosensory deprivation (Cools et al., 2002). In the present investigation, the task was characterized as predictable and voluntary, since the participants had visual (opened eyes) and somatosensory (effect of gravity on the upper limb) information, before and during the arm raise task (Kanekar & Aruin, 2015). In addition, auditory cues (metronome) helped to regulate the velocity of arm elevation during the different conditions. This allows for anticipated activation of the scapular muscles in order to maintain joint stability. In this context, the differences observed in the present study, as compared to the previous reports, can be attributed to the nature of the motor task employed in each study (Mendez-Rebolledo et al., 2016), and the simultaneous presence of fatigue and high velocity in the execution of the movements.

Based on the previous research, it is likely that fatigue is the determining condition for this modification in muscular latency during movement execution at high velocity. One possible explanation for this decrease in UT latency is the type of fiber in each compartment of the trapezius muscle. The LT has a high proportion of type I fibers (resistant to fatigue) while the UT has a high proportion of type II fibers (non-resistant to fatigue) (Lindman et al., 1990; Lindman et al., 1991; Larsson et al., 2001). Due to these histochemical characteristics, the fibers of the UT fatigue faster, generating overactivation and an increase in firing rate, in order to maintain scapular function

(Falla et al., 2009; Ge et al., 2012). On the contrary, the fibers of the LT and MT are more resistant to fatigue and maintain their activation with no major variations. This is based on the results by Westgaard and De Luca (2001) who showed that the inferior fibers of the trapezius muscle have a larger proportion of low threshold motor units which are usually associated with muscle fibers with higher aerobic capacity and therefore are able to activate for longer periods compared to high threshold motor units. Therefore, the observed changes in muscle recruitment might be explained by the different peripheral properties of the scapular muscles. However, it is also likely that central adjustments influenced the recruitment order as it has been shown that the central nervous system may change the recruitment strategy to satisfy the demands of the task (Strang & Berg, 2007; Mendez-Rebolledo et al., 2016). In this context, the large standard deviation (variability) of the muscle onset latencies of the groups may mask potential differences. This could be potentially explained by different neural strategies used by the participants during the arm elevation, despite that the demands of the task remained consistent for each individual condition

On the other hand, the results of the present study indicate that the activation latencies of the MT, LT, and SA muscles are not modified when the arm raise task is performed at varying velocities. These results are consistent with previous reports where MT, LT, and SA are activated prior to the AD muscle (shown as negative values for onset latencies), both in healthy non-athletes who performed a movement at low-velocity (Roy et al., 2008; Mendez-Rebolledo et al., 2016), and in healthy tennis players who executed a serve at high-velocity (Kibler et al., 2007). It is probable that the high demand of a high-velocity arm movement is addressed by a greater contribution of the scapular kinematics (Sugamoto et al., 2002; Prinold et al., 2013) and EMG amplitude

(Gaudet et al., 2017), without variations in the activation latency of MT, LT, and SA. These muscles are considered the main scapular stabilizers which allow dynamic control of the scapula during arm movements (Kibler et al., 2007; Boettcher et al., 2010), and therefore, are the main active muscles required in diverse environmental conditions.

4.2. Scapular muscle recruitment order and sport

The results of our investigation reveal a specific recruitment pattern of the scapular muscles, in the absence of fatigue, and during high and low velocity conditions: the stabilizing scapular muscles, i.e., MT, LT, and SA (Kibler et al., 2007; Boettcher et al., 2010; Phadke & Ludewig, 2013), are likely to be activated prior to the AD muscle, and the scapular mobilizing muscle, i.e., UT (Kibler et al., 2007; Boettcher et al., 2010; Phadke & Ludewig, 2013), is activated after the AD. This order of recruitment has been observed in a tennis serve (Kibler et al., 2007) and a baseball pitch (Hirashima et al., 2002), where the movements of the arm are performed at high-velocity.

In contrast, this muscle pattern varies with the simultaneous presence of fatigue and high velocity arm movement: the scapular mobilizing muscle is activated prior to the AD muscle, and the scapular stabilizing muscles are activated later. These results show that muscle fatigue or an increase in velocity alone do not substantially modify muscle activation latencies (Roy et al., 2008; Gaudet et al., 2017), but the simultaneous presence of muscle fatigue and high velocity movement contributes to the decrease in the activation latency of the UT, and the modification of muscle recruitment order. Where there is greater demand for velocity in a motor task, there is greater rotation of the scapula (Sugamoto et al., 2002; Prinold et al., 2013; Gaudet el al., 2017). This greater demand in the kinematics is reflected by the scapular muscles through a greater EMG amplitude of the stabilizing muscles (SA) (Gaudet et al., 2017) and, according to the results of this study, a relatively stable recruitment order: SA, LT, MT, AD, and UT. However, in the presence of muscular fatigue, the UT modifies its motor control strategy by decreasing its activation latency and considerably modifying the scapular recruitment pattern: UT, AD, SA, LT, and MT. According to our results, the decrease in UT muscle latency significantly influenced the muscular recruitment order, primarily because of the presence of fatigue during the high velocity arm movement. These fast movements are commonly observed in sport activities involving the upper limb, e.g., baseball, basketball, athletics (throwing), and volleyball (Hirashima et al., 2002; Kibler et al., 2007). In this context, it is likely that in the fatigued (high-velocity) condition, the UT was part of an anticipatory postural adjustment as the onset was prior to AD, which contrasted with the non-fatigued condition. Previous research has shown an over-activation of the UT in subjects with shoulder dysfunction (Ludewig & Cook, 2000; Larsen et al., 2013; Kara et al., 2017); therefore, it could be tempting to suggest that an earlier onset of UT activation during a fatiguing task could increase the risk of injury. However, the upper limb sports mentioned above may require an earlier activation of the UT during a fatigued condition to satisfy the demands of the movement. Therefore, this recruitment pattern would be necessary to enable the performance of the task. These observations (whether the earlier activation of the UT can be considered an adaptive or a mal-adaptive response), need to be confirmed in future studies comparing both healthy and injured populations.

4.3. Limitations

Despite the interesting findings reported in this study we must acknowledge some limitations. The muscle activation latency was based on a threshold of three standard deviations from the resting EMG. Di Fabio (1987) supports the use of this method due to its reliability and maximum comparability between studies. In addition, Hodges & Bui (1996) indicate that this criterion is widely used during dynamic contractions because it reduces the negative influence of artifacts and signal-to-noise ratio. In spite of this, it is necessary to use caution when making comparisons between studies, bearing in mind the method of obtaining muscle activation latency. In addition, the operational definition of arm movement velocity was in accordance with the study of Sugamoto et al. (2002). The low-velocity group executed the task with a velocity of four seconds per cycle of elevation, in a range of motion of 180°, and the high-velocity group executed the task with a velocity of two seconds per cycle. Other reports have indicated that the arm velocity reached during sports involving the upper limb may be higher (Prinold et al., 2013), possibly because of the rotational components of the movements used (e.g., rotation of the shoulder during a pitch). Another limitation of the current study is the lack of investigation of the deeper muscles, however, these muscles are difficult to assess with intramuscular EMG during highly dynamic tasks.

5. Conclusions

The simultaneous presence of muscle fatigue and high-velocity arm raise movement is associated with a decrease in the UT activation latency and a modification to the scapular muscle recruitment order. An increase in the arm raise velocity generates a greater demand on the scapular kinematics, which is dealt with by the scapular muscles through a relatively stable order of recruitment: SA, LT, MT, AD, and UT. However, in the presence of muscle fatigue, the UT modifies its motor control strategy by decreasing its activation latency, thereby considerably modifying the order of scapular recruitment: UT, AD, SA, LT, and MT. This study contributes to the understanding of several factors that can influence motor control strategy, especially UT activation latency, during the practice of overhead sports.

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Tables

Table 1. Scapular muscles onset latencies and multiple pairwise comparisons between velocities (low and high) and conditions (no-fatigue and fatigue) for upper trapezius.

Scapular Muscles	**No-fatigue/low-velocity**	**No-fatigue/high-velocity**	**Fatigue/low-velocity**	**Fatigue/high-velocity**
Upper trapezius onset latency (ms)	26.8 ± 31.8	16.5 ± 54.4	5.2 ± 55.3	-44.4 ± 56.8
Middle trapezius onset latency (ms)	-79.6 ± 53.1	-24.9 ± 50.8	19.4 ± 56.3	40.8 ± 41.7
Lower trapezius onset latency (ms)	-68.7 ± 63.2	-34.4 ± 34.7	12.6 ± 79.3	19.4 ± 49.2
Serratus anterior onset latency (ms)	-59.1 ± 38.4	-63.0 ± 44.0	-3.8 ± 55.1	4.7 ± 50.7
Upper trapezius	**Mean difference**	**95% CI of difference**	***P* value**	**Cohen's *d***
No-fatigue/low-velocity (vs) fatigue/low-velocity	21.6	-9.76 to 53.0	0.233	0.47
No-fatigue/low-velocity (vs) no-fatigue/high-velocity	10.3	-24.6 to 45.1	0.999	0.23
No-fatigue/low-velocity (vs) fatigue/high-velocity	71.2	7.7 to 134.7	0.008	1.54
No-fatigue/high-velocity (vs) fatigue/high-velocity	61	29.6 to 92.3	< 0.0001	1.09
Fatigue/low-velocity (vs) no-fatigue/high-velocity	11.3	- 74.8 to 52.2	0.350	0.20
Fatigue/low-velocity (vs) fatigue/high-velocity	49.6	14.8 to 84.5	0.003	0.88

95% CI, 95% confidence interval.

Table 2. Multiple pairwise comparisons between scapular muscles in each velocity (low and high) and codition (no-fatigue and fatigue).

Onset latency (ms)	**No-fatigue**				**Fatigue**			
Low-velocity	**Mean Dif**	**95% CI of Dif**	***P* value**	**Cohen's *d***	**Mean Dif**	**95% CI of Dif**	***P* value**	**Cohen's *d***
Anterior deltoid – upper trapezius	-26.8	-48.1 to -5.5	0.007	1.19	-5.2	-42.1 to 31.7	1.000	0.13
Anterior deltoid – midle trapezius	79.6	44.1 to 115.1	< 0.0001	2.11	-19.4	-57.0 to 18.2	1.000	0.48
Anterior deltoid – lower trapezius	68.7	26.4 to 110.9	< 0.0001	1.53	-12.6	-65.6 to 40.4	1.000	0.22
Anterior deltoid – serratus anterior	59.1	33.4 to 84.8	< 0.0001	2.17	3.9	-33.0 40.7	1.000	0.09
Upper trapezius – midle trapezius	106.4	63.6 to 149.1	< 0.0001	2.43	-14.2	-47.2 to 18.8	1.000	0.25
Upper trapezius – lower trapezius	95.5	44.8 to 146.2	< 0.0001	1.90	-7.4	-65.3 to 50.5	1.000	0.10
Upper trapezius – serratus anterior	85.9	52.8 to 119.1	< 0.0001	2.43	9.0	-33.3 to 51.4	1.000	0.16
Midle trapezius – lower trapezius	-10.9	-47.4 to 25.6	1.000	0.17	6.8	-46.3 to 59.9	1.000	0.09
Midle trapezius – serratus anterior	-20.4	-55.6 to 14.8	0.830	0.39	23.2	-14.4 to 60.9	0.666	0.41
Lower trapezius – serratus anterior	-9.5	-56.9 to 37.8	1.000	0.18	16.4	-23.2 to 56.0	1.000	0.24
High-velocity	**Mean Dif**	**95% CI of Dif**	***P* value**	***d***	**Mean Dif**	**95% CI of Dif**	***P* value**	***d***
Anterior deltoid – upper trapezius	-16.5	-52.9 to 19.9	1.000	0.42	44.4	6.4 to 82.4	0.014	1.10
Anterior deltoid – midle trapezius	24.9	-9.0 to 58.8	0.318	0.69	-40.8	-68.7 to -12.9	0.002	1.38
Anterior deltoid – lower trapezius	34.4	11.2 to 57.6	0.001	1.40	-19.4	-52.2 to 13.5	0.785	0.55
Anterior deltoid – serratus anterior	63.0	33.6 to 92.4	< 0.0001	2.02	-4.7	-38.6 to 29.2	1.000	0.13
Upper trapezius – midle trapezius	41.4	-0.7 to 83.6	0.057	0.78	-85.2	-122.8 to -47.6	< 0.0001	1.70
Upper trapezius – lower trapezius	50.9	12.1 to 89.7	0.005	1.11	-63.8	-113.2 to -14.5	0.006	1.20
Upper trapezius – serratus anterior	79.6	31.1 to 128.1	< 0.0001	1.60	-49.1	-88.9 to -9.4	0.009	0.91
Midle trapezius – lower trapezius	9.5	-20.6 to 39.5	1.000	0.21	21.4	-22.1 to 64.8	1.000	0.46
Midle trapezius – serratus anterior	38.1	3.0 to 73.3	0.027	0.80	36.1	5.3 to 66.8	0.014	0.77
Lower trapezius – serratus anterior	28.7	1.0 to 56.3	0.066	0.72	14.7	-29.3 to 58.7	1.000	0.29

Dif, difference; 95% CI, 95% confidence interval; *d*, effect size Cohen's *d*.